



INTELLIGENT MONITORING SYSTEM REVEALS NEW INFORMATION ABOUT THE CHAMPLAIN BRIDGE

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EXECUTIVE SUMMARY

The Champlain Bridge, constructed in 1957, is one of Canada's busiest and most economically critical bridges. This 3.4km-long bridge consists of as many as 50 simply supported spans, 50 to 53 m long, plus an elevated truss structure over the Saint Lawrence Seaway. Each span has a cross-section of seven precast post-tensioned girders supporting cast-in-place infill strips that constitute a deck with six traffic lanes. Like many other structures, Champlain Bridge is subjected to environmental, traffic or hydrological loads, which adversely affect the structural condition of the bridge. This structural degradation is further accelerated for the Champlain Bridge due to Montreal's cold climate, with snowfall and windy conditions, in addition to seasonal salting on the concrete deck. Consequently, structural degradation has been observed due to the corrosion of some of the post-tensioned strands in the main edge girders on the upstream and downstream side.

Structural degradations that are not timely diagnosed and treated could result in bridge service interruptions and even failures with economic and environmental consequences. Therefore, structural health monitoring (SHM) is a critical activity for bridges, including the Champlain Bridge, to ensure anomalies and out-of-spec trends are diagnosed on time. In fact, the Champlain Bridge is highly instrumented for SHM purposes. Each bridge span's edge girders are instrumented with three fiber optic sensors: one bending sensor in the middle measuring the lower fiber elongation and two shear sensors at either end inclined at 45°. There are 300 long measurement base OSMOS fiber optic sensors presently installed on the bridge. These sensors measure elongations as small as 2 micrometers with a very small time resolution of 0.02 seconds (or 50Hz). The sensor data is recorded or logged whenever a certain deformation threshold is reached during regular 24/7 traffic.

The installation of the fiber optic sensors on the Champlain Bridge began in 2006 with the edge beams of the first three spans on the Nun's island. Other spans were gradually added to the monitoring plan, and by 2015, all spans and 100 beams were instrumented. Initially, engineers analyzed data from small number of sensors; however, this became cumbersome with the increasing number of sensors installed and data recorded. Such data contains invaluable information about the bridge dynamic performance, health condition and safety under traffic load. However, interpreting this abundance of data (100MB of daily data) efficiently to extract this information cannot be performed manually. Manual calculations are prone to human error and incapable of performing more complex analysis accurately and in a timely fashion. In addition, conventional SHM practices based on manual inspections, data visualization and eyeballing are extremely time-consuming, labour intensive, and thus expensive and insufficient for the Champlain Bridge. A sophisticated tool is therefore needed to automate the data analysis process

and quickly and reliably transform raw sensor data into decision-ready information to be interpreted by structural engineers.

IntelliBRIDGE is a comprehensive software developed in Canada for automated, accurate and reliable sensor data analysis to support SHM activities of instrumented bridges. It integrates a broad spectrum of data monitoring, contextual visualization, database management, and data analytics functions ranging from simple statistical analysis and linear regression to advanced frequency calculations and state-of-the-art dynamic multi-variate data modeling.

The Jacques Cartier and Champlain Bridges Incorporated (JCCBI), the Crown corporation responsible for the Champlain Bridge and other major infrastructure in the region of Montreal, has used the software since August 2015. In this Project Profile, the early experiences of utilizing the tool to analyze instrumentation data acquired from the Champlain Bridge are presented to demonstrate its immeasurable operational and engineering benefits. Three cases or scenarios of particular importance are presented:

- (1) **Automated Time-Domain Analysis of Dynamic Data during Normal Traffic:** The software automatically identifies dynamic events (related to the bridge normal traffic) in the recorded data and very quickly calculates maximum Tension, maximum Compression and peak-to-peak deformations for every event. Previously, only peak-to-peak deformations; i.e., the distance between maximum Tension and Compression, were calculated manually by eyeballing data from a subset of dynamic events (not all of them). In fact, the peak-to-peak measure was selected to halve the number of required manual calculations. However, the newly automated calculations and time trending of both Tension and Compression has revealed very interesting and novel information about the structural health of the bridge that was missed previously.
- (2) **Automated Frequency-Domain Analysis of Dynamic Data during Normal Traffic:** Automated vibration analysis has allowed engineers to very quickly and reliably monitor and verify the effects of recent modular trusses installations on the bridge. These trusses are added to increase the stiffness of the damaged girders. Since the mass of the trusses is negligible compared to that of the span, the increased stiffness is expected to increase the first fundamental frequency of the span free vibrations. This analysis has revealed increase in fundamental frequency from 2.3Hz to 2.5Hz within a very short period of time after truss installation.
- (3) **Automated Load Test Data Analysis:** Presently, load tests are performed on the Champlain Bridge once a month in order to detect bridge spans that are more compliant to deformation than the design expectations or other spans of the bridge. The 300 fiber optic sensors are used to measure “bending” and “shear” deformations. During the load test, starting typically around midnight, three lanes of the bridge in one direction are first closed to traffic, then a heavy truck (48 T) crosses the bridge at a fixed speed of 10 km/h followed by a lighter truck (30 T) driving at the same speed but at a distance of about three bridge spans (almost 150m). The public traffic follows after the police cars escorting the trucks. The same procedure is performed in the other direction. The data recorded from fiber optic sensors during the load test were manually analyzed to determine the health state of the bridge spans. This analysis involved three steps: (a) Manually detect and isolate the deformation responses to both the heavy and the light truck passage, and differentiate them from other responses in the entire time-series of the recorded data during load test; (b) Manually calculate the peak amplitudes for bending deformations in the detected and isolated responses; and (c) Manually calculate the corresponding shear deformations. This labour intensive process took typically a week to complete. The automation has brought this time down to several minutes.